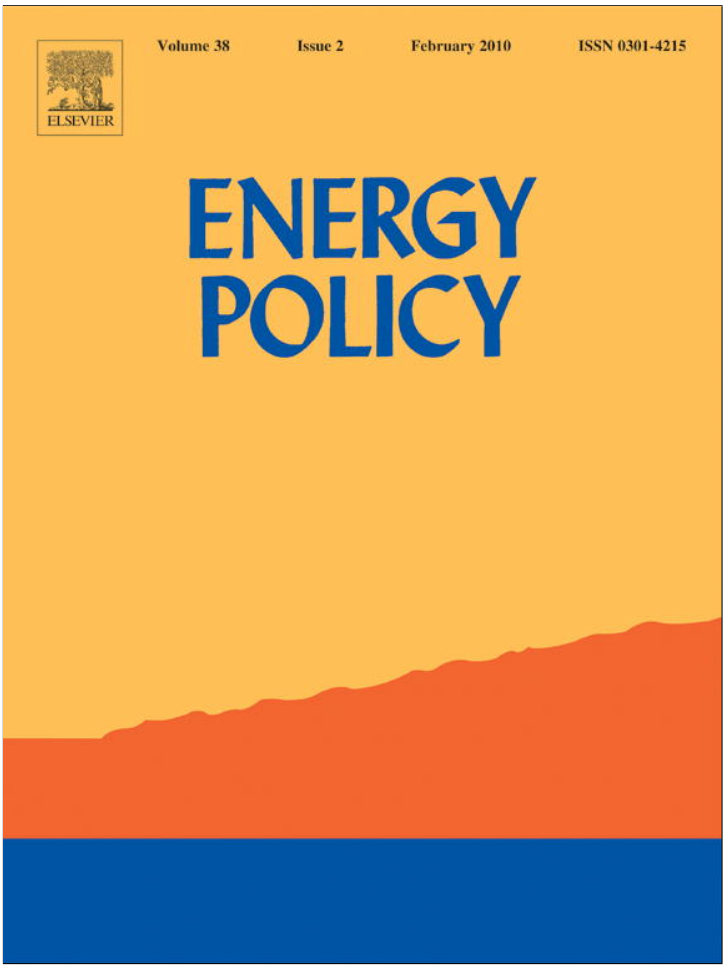

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China's oil use, 1990–2008

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ABSTRACT

Over the past two decades, China's oil demand has risen steeply. In 1990, it was only about 25% higher than that of 1978, the year economic reform was introduced. By 2008, it had reached 396.0 million tons, roughly four times the 1978 level, making China the second largest oil user worldwide. The country became a net oil importer in 1993, and between 1993 and 2008, its net import dependency—a yardstick for energy security—soared from 7.5% to 50.0%. China's increased demand for oil has made the country a global energy player of critical importance. Although the literature on the global implications of China's oil use has proliferated, relatively few studies have attempted to examine "how China uses oil." Hence, this study covers every oil-consuming facility and sector in China, exploring the patterns of, and factors involved in, oil demand by power plants, oil refineries, heat plants and, gas-works, and industrial, transport, agricultural, household and commercial sectors. It concludes that in virtually all sectors in China, oil demand will grow, with transport and industry leading the way.

1. Introduction

The international price of oil (NYMEX crude) climbed from about $25/barrel in March 2003 to a record high of $147/barrel in July 2008 (EIA, 2009b). Many attributed the price increase to China's oil demand, as this country accounted for 37.1% of the increase in world oil consumption between 2003 and 2007, even though it represented 38.2% of the growth in world oil demand from 2000 to 2003 (BP, 2009, p. 12). Although some forecasted that the price would rise to $200/barrel, it suddenly plunged to below $50 in mid-November 2008 and fluctuated between $35 and $75 from December 2008 to September 2009 (EIA, 2009b).

The drop in oil price mainly resulted from a financial tsunami, which reduced oil demand. World oil demand is expected to fall in 2009 (Kwiatkowski, 2009), while Chinese oil consumption in 2009 is forecasted to be 0.4 % lower than that in 2008 (IEA 2009b, p. 13).

However, China's leaders believe that in the long run domestic oil demand growth will accelerate. They are making judicious use of the current situation to protect the country's future energy security. With US$2 trillion in foreign currency reserves, they have recently signed multi-billion-dollar cash-for-oil agreements with a number of oil-producing countries that have run short of money for investment,[1] including Russia, Kazakhstan, Brazil, Venezuela and Angola (Cala, 2009). In June 2009, China's national oil companies appeared to secure access to substantial oil and gas reserves in Iran and Iraq (Andrews-Speed, 2009). Clearly, China will continue to be a major player in the world oil market.

Although the role of China in the world oil industry has attracted increased research attention in recent years, comprehensive studies of "how China uses oil" are relatively few (Leung, 2009). Therefore, this study explores the patterns of, and factors involved in, oil demand by every oil-consuming facility and sector, including power plants, oil refineries, heat plants, and gas-works, and industrial, transport, agricultural, household and commercial sectors, to shed light on future oil demand.[2]

This paper consists of five parts. Next, we provide an overview of China's oil economy. Then, we analyze transformation consumption of oil and end-use consumption of oil, respectively. Lastly, we discuss the major findings and their implications.

2. China's oil economy

The People's Republic of China, a large country, has a territory of 9.6 million km^2 and had a population of 1.328 billion at the end of 2008 (NBS, 2009, p. 1, 38). Since economic reform began in late 1978, China's real gross domestic product (GDP) has grown rapidly, with an average annual growth rate of 9.8% during 1978–2008 (CEIC Data, 2009). China's nominal GDP reached US$4401.6

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[1] The sudden plunge in oil prices should spell major trouble to oil-producing countries. Russia's 2009 budget was designed based on oil at $95/b, and Venezuela's and India's at $60/b (Escobar, 2009, p. 49).

[2] For sectoral analysis of energy in developing countries, see ESCAP (1991) and IEA (1994).

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billion at the end of 2008, making it the world's third largest economy (IMF, 2009).

A country's demand for energy tends to mirror the size of its economy. Hence, the total primary energy consumption (PEC) of China has also increased rapidly, with an average annual growth rate of 5.6 % during 1978–2008 (CEIC Data, 2009). China's PEC amounted to 2850.0 million tons of coal equivalent (Mtce) in 2008, second only to that of the United States (NBS, 2009, p. 145).

Table 1
China's primary energy consumption and its composition[a], 1990–2008.
Source: China Statistical Yearbook 2008, CD-ROM.

	Total	Coal	Oil	Natural gas	Primary electricity[b]
	Mtce	%	%	%	%
1990	987.0	76.2	16.6	2.1	5.1
1991	1037.8	76.1	17.1	2.0	4.8
1992	1091.7	75.7	17.5	1.9	4.9
1993	1159.9	74.7	18.2	1.9	5.2
1994	1227.4	75.0	17.4	1.9	5.7
1995	1311.8	74.6	17.5	1.8	6.1
1996	1389.5	74.7	18.0	1.8	5.5
1997	1378.0	71.7	20.4	1.7	6.2
1998	1322.1	69.6	21.5	2.2	6.7
1999	1338.3	69.1	22.6	2.1	6.2
2000	1385.5	67.8	23.2	2.4	6.7
2001	1432.0	66.7	22.9	2.6	7.9
2002	1518.0	66.3	23.4	2.6	7.7
2003	1749.9	68.4	22.2	2.6	6.8
2004	2032.3	68.0	22.3	2.6	7.1
2005	2233.2	69.1	21.0	2.8	7.1
2006	2462.7	69.4	20.4	3.0	7.2
2007	2654.8	69.5	19.7	3.5	7.3
2008	2850.0	68.7	18.7	3.8	8.9

China Statistical Abstract 2009, p. 145.

[a] Only commercial energy is included, but one should bear in mind that non-commercial biomass energy is still widely consumed, particularly in rural China, amounting to 263.0 Mtce in 1990 and 263.0 Mtce in 2007.

[b] Primary electricity includes hydro-, nuclear and wind electricity. Only commercial energy is included.

Oil did not play a major role in China's fuel mix during 1990–2008 (Table 1). In this period, the share of coal decreased from 76.2% to 68.7%, whereas that of oil, primary electricity, and natural gas increased from 16.6% to 18.7%, 5.1–8.9% and 2.1–3.8%, respectively. Coal, a dirty fuel, is being replaced by other cleaner energies, including natural gas and renewable energies. This energy shift is most apparent in industrial, household and commercial sectors. The relation between oil and coal is less linear. Coal now plays a larger role in transformation sector while oil has gained importance in end-use sector. Specifically, coal has gradually replaced oil in power plants, heat supply and gas works whereas oil has progressively replaced coal in transport, agricultural, household and commercial sectors. In industrial sector, there has been a temporary rebound in coal and a decline in oil since 2003, as heavy industry, mainly fuelled by coal, grew more stunningly (Rosen and Houser, 2007).

Moreover, given the constraint of supply, the impact of natural gas on oil is confined to household and commercial sectors, where the competition between natural gas and LPG takes place. Up to the moment, power plants and factories, the traditional big users of natural gas, use relatively little natural gas: this type of hydrocarbon represented 1.1% of total gross fuel inputs to steam power generation and 4.1% of industrial final energy use in 2007, respectively. For industrial feedstock (non-energy use), natural gas grew from 7.2 Mtce in 1991 to 13.3 Mtce in 2007 but oil also increased from 27.8 to 47.6 Mtce (DITS, various years).

Although oil has not traditionally taken up a significant proportion of total energy use, ensuring a reliable and adequate supply of oil in China has become increasingly challenging. Whereas indigenous oil production has increased slowly—climbing from 138.3 million tons (Mt) in 1990 to 197.8 Mt in 2008—China's oil consumption has grown rapidly from 114.9 to 396.0 Mt in the same period, yielding an average annual growth rate of 7.1% (Table 2). China's oil consumption surpassed its oil production in 1993, and as a result, the country became a net importer of oil. Between 1993 and 2008, its net oil import dependency—an important yardstick for energy security—soared from 7.5% to 50.0%.

Oil security and energy security are increasingly the same issue for China's leaders. According to Yergin (1988, p. 112), the

Table 2
China's oil production, consumption and trade, 1990–2008.
Source: China Energy Statistical Yearbook, various issues and pages.

	Oil production	Oil consumption	Oil imports	Exports oil	Net oil imports	Net import dependency[a]
	Mt	Mt	Mt	Mt	Mt	%
1990	138.3	114.9	7.6	31.1	−23.5	−20.5
1991	141.0	123.8	12.5	29.3	−16.8	−13.6
1992	142.1	133.6	21.2	28.6	−7.3	−5.5
1993	145.2	147.2	36.2	25.1	11.1	7.5
1994	146.1	149.5	29.0	23.8	5.2	3.5
1995	150.1	160.6	36.7	24.5	12.2	7.6
1996	157.3	174.3	45.4	27.0	18.4	10.6
1997	160.7	194.1	67.9	28.2	39.7	20.5
1998	161.0	198.2	57.4	23.3	34.1	17.2
1999	160.0	210.7	64.8	16.4	48.4	23.0
2000	163.0	224.4	97.5	21.7	75.8	33.8
2001	164.0	228.4	91.2	20.5	70.7	31.0
2002	167.0	247.9	102.7	21.4	81.3	32.8
2003	169.6	271.3	131.9	25.4	106.5	39.3
2004	175.9	317.0	172.9	22.4	150.5	47.5
2005	181.4	325.3	171.6	28.9	142.8	43.9
2006	184.8	348.8	194.5	26.3	168.3	48.2
2007	186.3	366.5	211.4	26.6	184.8	50.4
2008[b]	197.8	396.0	–	–	197.2	50.0

EIA (2009a), http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=CH.

[a] Net import dependency stands for the percentage of the amount of net oil imports over the amount of total oil consumption.

[b] Estimates of the EIA (2009a).

objective of energy security is "to assure adequate, reliable supplies of energy at reasonable prices and in ways that do not jeopardize major national values and objectives". So far, oil is the only form of energy for which China has to meet the demand by massive net imports.

In addition, oil underpins "national values and objectives." Since the introduction of the socialist market economy, the political legitimacy of the Communist Party of China (CPC) has been eroded: the Party needs to find a way to maintain and stabilize communist governance in an increasingly capitalist country. It has therefore tried to gain popular support by meeting people's nationalist and economic expectations, which include (i) continued economic growth, (ii) continued rise in living standards, (iii) maintenance of territorial integrity and (iv) continued growth as a global power. As no efficient and economical substitutes exist for diesel, gasoline and jet fuel (aviation kerosene) for transport and the military, oil is a necessity to the economy and military (Downs, 2006). Thus, a reliable and adequate supply of oil at reasonable prices is crucial to national values and objectives and underpins, in part, the CPC's governance.

3. Transformation consumption of oil

To distinguish raw from processed forms of energy, energy statisticians classify energy as primary or secondary. Primary energy refers to crude, unprocessed forms of energy gained directly from nature, which usually need to be refined or converted into other forms as their direct use is often wasteful, inconvenient, polluting or incompatible with appliances and equipment. Refined, converted or processed forms of energy are referred to as secondary energy, and it is noteworthy that most of the energy consumed directly by citizens is in this form.[3] During the process of transformation, the second law of thermodynamics dictates that a certain proportion of the energy is unavoidably lost, regardless of the level of technology used. We refer to such loss as transformation consumption of energy.

During 1990–2007, transformation consumption of oil was eclipsed by the rapid growth in end-use consumption—whereas the former increased slowly from 19.3 to 26.0 Mt, the latter soared from 93.0 to 337.7 Mt. At the national level, the proportion of transformation use of oil declined from 16.8% to 7.1%, whereas that of end-use oil increased from 80.9% to 92.1% (Table 3).

The composition of transformation oil consumption changed dramatically during 1990–2007 (Table 4). First, refinery oil demand quadrupled during this period, increasing from 3.0 to 12.8 Mt, with its share of overall transformation oil demand more than tripling, from 15.5% to 49.2%. Second, power generation oil use fell from 12.3 to 8.8 Mt, with its share plummeting from 63.7% to 33.8%. Third, oil used for district heating stayed at around 4 Mt, with its share decreasing from 18.7% to 16.5%. Lastly, gas manufacturing oil use was negligible, with its share decreasing from 2.1% to less than 0.1%.

3.1. Refinery oil use

International experience shows that refining capacity has broadly grown and declined in response to shifts in demand for oil products (Walls, 2009). The sharp rise in refinery oil use during 1990–2007 mainly resulted from the expansion of refinery capacity and increase in the amount of oil refined. China's refinery capacity grew from 2.9 million barrels per day (Mb/d) in 1990 to 7.7 Mb/d in 2007—almost the same as that of the whole Middle East—making China the second largest refiner in terms of capacity, next to the US (BP, 2009, p. 19). China's refinery throughput increased from 2.2 to 6.6 Mb/d during this period (DITS, various years).

China's refining sector has expanded quickly in line with the interests of three parties (Collins, 2008). First, among oil-exporting countries, helping China to expand and upgrade its refining industry ensures a market for their crude, especially low-quality crude. For example, most of the Middle East's crude oil is low in quality: it is heavy, sour and sometimes acidic, and not all refiners are able to process these kinds of crude. Previously, China's refinery industry lacked the capacity to

[3] In practice, total primary energy consumption includes the net imports of secondary energy, because the net losses of producing secondary energy products do not occur within the borders of the importing countries. For example, China's total oil consumption includes the consumption of crude oil and consumption of net imports of oil products.

Table 3
Transformation and end-use consumption of oil in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Transformation		End use		Losses & errors[a]		Total
	Mt	%	Mt	%	Mt	%	Mt
1990	19.3	*16.8*	93.0	*80.9*	2.6	*2.3*	114.9
1991	19.4	*15.7*	101.8	*82.2*	2.6	*2.1*	123.8
1992	22.0	*16.5*	109.0	*81.6*	2.6	*1.9*	133.6
1993	25.0	*17.0*	119.7	*81.3*	2.5	*1.7*	147.2
1994	22.5	*15.1*	124.6	*83.3*	2.4	*1.6*	149.5
1995	22.3	*13.9*	136.7	*85.1*	1.6	*1.0*	160.6
1996	19.7	*11.3*	153.0	*87.8*	1.6	*0.9*	174.3
1997	24.5	*12.6*	167.8	*86.5*	1.8	*0.9*	194.1
1998	21.1	*10.6*	175.0	*88.3*	2.1	*1.1*	198.2
1999	22.2	*10.5*	186.6	*88.6*	1.9	*0.9*	210.7
2000	23.5	*10.5*	199.0	*88.7*	1.9	*0.8*	224.4
2001	22.9	*10.0*	203.5	*89.1*	2.0	*0.9*	228.4
2002	26.1	*10.5*	219.8	*88.7*	2.0	*0.8*	247.9
2003	29.0	*10.7*	240.7	*88.7*	1.6	*0.6*	271.3
2004	34.9	*11.0*	280.7	*88.5*	1.4	*0.4*	317.0
2005	31.9	*9.8*	291.9	*89.7*	1.5	*0.5*	325.3
2006	30.6	*8.8*	317.7	*91.1*	0.5	*0.1*	348.8
2007	26.0	*7.1*	337.7	*92.1*	2.8	*0.8*	366.5

[a] "Losses & Errors" stands for oil losses during production and transport and statistical errors.

Table 4
Transformation consumption of oil by subsector, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Oil refineries		Power plants		Heat plants		Gasworks		Total
	Mt	%	Mt	%	Mt	%	Mt	%	Mt
1990	3.0	*15.5*	12.3	*63.7*	3.6	*18.7*	0.4	*2.1*	19.3
1991	2.9	*14.9*	12.7	*65.5*	3.4	*17.5*	0.5	*2.6*	19.4
1992	5.1	*23.2*	13.0	*59.1*	3.3	*15.0*	0.5	*2.3*	22.0
1993	3.5	*14.0*	16.0	*64.0*	5.1	*20.4*	0.5	*2.0*	25.0
1994	4.5	*20.0*	11.8	*52.4*	5.6	*24.9*	0.7	*3.1*	22.5
1995	4.2	*18.8*	13.6	*61.0*	4.0	*17.9*	0.5	*2.2*	22.3
1996	2.7	*13.7*	12.4	*62.9*	4.0	*20.3*	0.6	*3.0*	19.7
1997	3.8	*15.5*	16.6	*67.8*	3.6	*14.7*	0.5	*2.0*	24.5
1998	3.1	*14.7*	13.0	*61.6*	4.6	*21.8*	0.4	*1.9*	21.1
1999	5.7	*25.7*	12.3	*55.4*	3.9	*17.6*	0.3	*1.4*	22.2
2000	7.2	*30.6*	11.8	*50.2*	4.3	*18.3*	0.3	*1.3*	23.5
2001	6.2	*27.1*	12.1	*52.8*	4.4	*19.2*	0.2	*0.9*	22.9
2002	8.9	*34.1*	12.8	*49.0*	4.2	*16.1*	0.2	*0.8*	26.1
2003	9.7	*33.4*	14.9	*51.4*	4.2	*14.5*	0.2	*0.7*	29.0
2004	12.0	*34.4*	18.6	*53.3*	4.2	*12.0*	0.1	*0.3*	34.9
2005	11.7	*36.7*	16.0	*50.2*	4.1	*12.9*	0.1	*0.3*	31.9
2006	12.8	*41.8*	13.4	*43.8*	4.3	*14.1*	0.1	*0.3*	30.6
2007	12.8	*49.2*	8.8	*33.8*	4.3	*16.5*	0.0[a]	*0.0*	26.0

[a] Gasworks oil consumption in 2007 amounted to 49,600 tons.

process low-quality crude because it was set up for refining domestic crude oil, which is mostly low sulfur, or "sweet," crude oil. Hence, by helping this industry upgrade its capacity, oil-exporting countries in the Middle East can enlarge their market share in China (Bahgat, 2007).

Second, for the Chinese government, refining expansion means that more oil products can be gained from domestic production. This not only helps safeguard national oil security by limiting the rising dependency on imports but also, to some extent, helps the government to keep domestic fuel supplies at domestically affordable prices. In addition, many of the newly built refineries have equipment that can process heavy, high-sulfur and acidic crudes. With greater refining capacity to refine low-quality crudes, China can import crude from a wider range of suppliers. This is also in line with the strategy of import diversification, an important element of energy security policy.

Third, to some extent, the capacity expansion of China's refineries means more business, as the refiners can produce and sell more oil products, which is important as domestic demand for oil products has surged. Furthermore, expanding capacity in the form of green-field projects or joint-venture cooperation also gives refiners a chance to obtain advanced refinery technology and managerial know-how. Also, because refineries can process crude from a wider range of suppliers, oil acquisition costs are reduced, as low-quality crude oil is cheaper,[4] which also enhances import flexibility.

The increased refining capacity utilization rate has also reflected more loss of oil. Statistics show an increase in not only refining capacity but also capacity utilization rates in China. For example, the utilization rate of Sinopec's refining capacity increased from 70.0% in 1990 to 94.0% in 2007 (Wang, 1999, p. 141; Sinopec, 2009, p. 19). Although the previous utilization rate was uneconomically low, the rapid expansion in Chinese oil demand has rationalized refinery utilization.

Although using low-quality crude oil lowers oil acquisition costs, enhances import flexibility and maintains energy security, it at the same time bears environmental costs (Bradsher, 2004). The switch to high-sulfur crude oil, for example, could contribute to air pollution and reduce conversion efficiency of refineries.

Sulfur forms noxious gases like sulfur oxides and causes diesel engines to spew more soot. If properly processed, high-sulfur crude oil is not necessarily transformed into high-sulfur oil products and sources of air pollution, but some institutional factors have prevented the proper handling from happening. First, Chinese ceilings for sulfur in fuel, in general, are considerably more lax than those in the United States or Europe. Second, while China's main refiners, i.e. Sinopec and CNPC, have been investing heavily to improve their abilities to remove sulfur, many small refiners owned by private companies or local governments, without the abilities or willingness to improve the air, continued to buy cheap high-sulfur crude and sell high-sulfur oil products to consumers. This can be borne out by the fact that hydro-treating capacity, required to reduce impurities such as sulfur and improve product quality, has increased more slowly (Walls, 2009). Besides, although some cities, like Shanghai and Beijing, have stricter emissions standards and do not allow sales of low-quality oil products, widespread smuggling of cheaper high-sulfur fuel from smaller cities and rural areas have limited the benefits of these efforts.

Consequently, high-acid crude would be more desirable than high-sulfur crude to China as the former yields a larger volume of low-sulfur product at lower costs and can be blended with domestic low-sulfur crudes, better corresponding with its refining infrastructure and increasingly stringent emissions standards.

Furthermore, the gradual reduction in the energy efficiency of the Chinese refinery industry—caused by the need for further processing—has also contributed to the increase in petroleum refinery oil consumption. Changes in both the quality of the crude oil being refined and petroleum product specifications on the demand side have contributed to the reduction in efficiency by necessitating the broader operation of second-processing facilities.

First, to process low-quality crude, Chinese refineries need to utilize second processing more intensively, such as hydro-treating, and oil conversion losses increase.

Second, the shifts in petroleum product specifications on the demand side have created a greater need for second-processing facilities. The pattern of Chinese oil consumption has changed since 1990. People now consume more light petroleum products, such as LPG and diesel, than heavy products, such as fuel oil. To meet this change in demand, Chinese refiners rely on second processing, such as hydro-cracking, to yield a higher proportion of light products from a given barrel of crude oil.

As a result, oil conversion losses have increased. Refining efficiency has stayed well over 90% since 1990, but declined marginally from 98.1% in 1991 to 97.2% in 2007 (DITS, various years).

3.2. Power generation oil use

Coal-fired generation has dominated China's power sector, with the share of coal in total gross fuel inputs into steam power generation rising further from 91.1% in 1990 to 96.1% in 2007 (DITS, various years). The continuous decline in the relative importance of power generation oil demand can be traced back to the late 1970s. Oil-fired generation was encouraged in the 1960s and 1970s after the discovery of and development of Daqing oilfield in Heilongjiang province, the largest Chinese oilfield. However, the share of oil-fired to total steam generation capacity peaked at 27.1% in 1979 (Zhu, 2001), because Chinese leaders decided to save oil for exports in exchange for hard currency after the quadrupling of international oil prices induced by the oil crises in the 1970s (Chow, 1992). Although China's oil exports have declined since the mid-1980s, the role of oil-fired generation has not been restored because of increased oil demand in other sectors, especially industry and transport.[5] As a result, the share of oil in total energy inputs into steam generation dropped from 8.3% in 1990 to 1.4% in 2007, and the amount of oil used for steam power generation fell from 12.3 to 8.8 Mt in the same period, even though the total amount of electricity generated in China grew immensely from 621.2 terawatt-hours (TWh) to 3281.6 TWh (DITS, various years).

However, evidence shows that Chinese oil-fired generation will not disappear completely. First, oil-fired generation is

[4] A spokesman for Sinopec, China's biggest refining company, told The New York Times in 2004 that his company was aggressively importing high-sulfur oil because it was $1 a barrel cheaper than sweet crude. The added cost to Sinopec of removing sulfur in the refining process to meet Chinese national standards was only 10 cents a barrel (Bradsher, 2004). While the NYMEX oil prices were around $40–50 a barrel in 2004, it skyrocketed in subsequent years. The incentive to reduce oil acquisition costs by importing more lower-quality crude was therefore evident and comprehensible.

[5] China's leaders would have considered broader use of oil-fired generation if it were more energy efficient and environment-friendly than coal-fired generation. However, the energy efficiency of the former is only slightly higher than that of the latter. For example, in 2003, the energy efficiency of oil-fired generation, on average, was 34% and that of coal-fired generation 33%. In addition, it has been reported that the quality of heavy fuel oil used for Chinese power generation is surprisingly poor—in some cases, the burning of this oil releases more particulate matter and nitrogen oxides than the burning of coal (see Graus et al., 2007; Zhu, 2001).

economically sound for peak lopping. Second, when the country faces electricity shortages or power blackouts, oil-fired generation, as a form of private power generation, is often required. China faced serious power shortages in the summer of 2004, with 26 out of 31 provinces suffering from electricity imbalances (People's Daily Online, 2006). To cope with this crisis, many factories bought a huge amount of diesel and used diesel generators to try to meet their own demand for electricity. This action "unexpectedly" increased the country's oil imports, and caught worldwide attention because of its impact on international oil prices. Alhajji (2007) blames the International Energy Agency (IEA) for its failure to see the linkage between power shortages and oil demand for power generation, and its resulting ill-informed projection of Chinese oil demand. This case indicates that the impact of oil-fired generation on Chinese oil consumption should not be overlooked.

3.3. Heat supply and gas-works oil use

Two factors are responsible for the decline in the importance of oil in heat plants and gasworks. First, oil was intentionally saved for other sectors. Second, the cost of oil is higher than that of coal, especially when environmental regulations on coal are relaxed and the price of oil is high. As a result, the share of oil in total energy inputs into heat plants decreased from 18.7% in 1990 to 5.3% in 2007 and that for gas works decreased from 18.1% to 3.5% in the same period (DITS, various years).

4. End-use consumption of oil

The pattern of end-use oil consumption also changed tremendously during 1990–2007, with a conspicuous reduction in industry and expansion in transport (Table 5). The share of household demand expanded, that of agricultural demand shrank, and that of commercial demand changed relatively little.

4.1. Industrial oil use

Given its dominance in the Chinese economy, industry is unsurprisingly the largest energy and oil consumer in China. As in many developing countries, industrialization has been embraced in China as a means to develop the country. The reallocation of resources, including excess supplies of rural labor, to the more economically efficient, higher value-added industrial sector has accelerated economic growth and led to an increase in personal income. This in turn has alleviated the longstanding poverty problem and generated an internal demand for domestic goods and services, so that sustainable economic growth can be reached. Since its entry into the World Trade Organization (WTO), China has accelerated the development of the industrial sector and emerged as a global manufacturing center.

Industry, the service sector, and agriculture respectively accounted for 48.6%, 40.1% and 11.3% of the GDP in 2007 (NBS, various years). Industry's dominance in the economy mirrors its significance in the energy and oil markets: industrial energy consumption amounted to 1304.3 Mtce in 2007, representing 71.1% of total end-use energy (DITS, various years), and its oil consumption reached 142.3 Mt in 2007, accounting for 42.1% of total end-use oil demand.

Heavy industrialization is another important factor driving industrial energy consumption. From 1990 to 2007, the share of heavy industry in overall industrial outputs rose dramatically from 50.6% to 70.5% (NBS, various years). As heavy industry tends to be more energy intensive, industrial energy consumption growth sped up.

There are three social and economic forces behind the recent growth in heavy industry in China. The first force is urbanization. Turning a rural area into an urban environment involves massive infrastructure expansion and upgrading. The construction of buildings and facilities, for example, requires industrial materials ranging from steel to cement. The second force is the government's pro-auto policy. The government released a massive highway construction plan in 1998 (Gallagher, 2006), which required concrete, metals and chemicals. The third force stems from the backward linkage of light industry. The development of light industry requires the machinery, equipment and raw materials supplied by heavy industry. Therefore, its development has led to the expansion of heavy industry.

Contrary to popular assumption, the rapid development of industry has not strengthened the role of industrial oil demand in China; on the contrary, the share of industrial oil demand declined from 59.2% in 1990 to 42.1% in 2007 (Table 5), although the share of industrial energy demand grew from 64.4% to 71.1% in the same period (DITS, various years).

Table 5
End-use consumption of oil by sector, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Agriculture		Industry		Transport		Household		Commerce		End-use total
	Mt	%	Mt	%	Mt	%	Mt	%	Mt	%	Mt
1990	10.3	*11.1*	55.1	*59.2*	16.4	*17.6*	2.8	*3.0*	8.4	*9.0*	93.0
1991	10.7	*10.5*	59.1	*58.1*	18.3	*18.0*	3.2	*3.1*	10.5	*10.3*	101.8
1992	10.7	*9.8*	61.2	*56.1*	20.4	*18.7*	3.6	*3.3*	13.1	*12.0*	109.0
1993	10.6	*8.9*	63.7	*53.2*	22.5	*18.8*	4.2	*3.5*	18.7	*15.6*	119.7
1994	10.9	*8.7*	69.3	*55.6*	23.5	*18.9*	5.2	*4.2*	15.7	*12.6*	124.6
1995	12.0	*8.8*	73.4	*53.7*	27.3	*20.0*	6.8	*5.0*	17.2	*12.6*	136.7
1996	12.2	*8.0*	82.8	*54.1*	28.0	*18.3*	8.8	*5.8*	21.2	*13.9*	153.0
1997	12.6	*7.5*	88.2	*52.6*	35.8	*21.3*	9.4	*5.6*	21.8	*13.0*	167.8
1998	12.9	*7.4*	90.1	*51.5*	40.9	*23.4*	9.8	*5.6*	21.3	*12.2*	175.0
1999	14.2	*7.6*	89.2	*47.8*	48.5	*26.0*	11.3	*6.1*	23.4	*12.5*	186.6
2000	15.0	*7.5*	93.6	*47.0*	53.5	*26.9*	12.6	*6.3*	24.3	*12.2*	199.0
2001	15.7	*7.7*	94.3	*46.3*	55.4	*27.2*	12.9	*6.3*	25.2	*12.4*	203.5
2002	16.7	*7.6*	102.6	*46.7*	60.0	*27.3*	14.8	*6.7*	25.7	*11.7*	219.8
2003	16.8	*7.0*	111.9	*46.5*	69.6	*28.9*	16.4	*6.8*	26.0	*10.8*	240.7
2004	20.0	*7.1*	127.7	*45.5*	85.0	*30.3*	17.8	*6.3*	30.2	*10.8*	280.7
2005	20.7	*7.1*	127.5	*43.7*	95.8	*32.8*	17.9	*6.1*	30.0	*10.3*	291.9
2006	22.1	*7.0*	135.2	*42.6*	109.7	*34.5*	19.9	*6.3*	30.8	*9.7*	317.7
2007	21.3	*6.3*	142.3	*42.1*	121.3	*35.9*	22.7	*6.7*	30.1	*8.9*	337.7

Table 6
Fuel mix of industry[a] in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Total Mtce	Coal[b] %	Electricity %	Oil %	Heat %	MG[c] %	NG[d] %	Other %
1990	498.0	65.7	9.9	15.8	3.5	1.9	3.2	0.0
1991	521.9	64.6	10.2	16.2	3.7	2.0	3.3	0.0
1992	551.2	64.9	10.7	15.9	3.8	1.7	3.0	0.0
1993	590.9	64.0	11.2	15.4	4.5	2.0	2.9	0.0
1994	629.9	63.2	11.3	15.8	5.0	1.8	2.9	0.0
1995	702.2	62.0	11.1	15.0	4.4	4.2	2.7	0.6
1996	728.6	61.5	11.3	16.3	4.4	3.7	2.7	0.1
1997	719.1	58.9	11.8	18.1	4.5	3.6	2.7	0.3
1998	702.5	58.1	12.2	18.4	5.0	3.3	2.8	0.2
1999	659.9	53.5	15.1	19.0	5.6	3.2	3.2	0.5
2000	664.7	50.6	16.4	19.8	6.0	3.3	3.4	0.4
2001	674.5	48.9	17.6	19.7	6.2	3.4	3.7	0.5
2002	709.7	47.0	18.9	20.3	6.3	3.3	3.7	0.4
2003	841.1	49.7	18.7	18.7	5.5	3.2	3.8	0.4
2004	1,011.3	52.7	18.3	17.6	4.8	2.9	3.3	0.4
2005	1,120.3	52.8	18.7	15.9	5.1	3.6	3.5	0.5
2006	1,214.6	52.0	19.9	15.6	5.0	3.4	3.8	0.3
2007	1,304.3	50.4	21.6	15.2	4.9	3.5	4.1	0.3

[a] Energy use of construction is subsumed under this sector, following international practice.
[b] Coal includes coke products.
[c] MG=manufactured gas.
[d] NG=natural gas.

Table 7
Fuel mix of transport in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Total Mtce	Oil %	Coal %	Electricity %	Other %
1990	40.1	58.6	38.6	2.6	0.2
1991	42.0	62.5	34.5	2.8	0.2
1992	44.1	66.2	30.5	3.1	0.1
1993	46.4	69.4	27.1	3.2	0.3
1994	46.3	72.6	23.5	3.5	0.3
1995	50.5	77.3	18.8	3.6	0.3
1996	50.7	79.0	16.7	3.9	0.4
1997	64.3	79.7	16.0	4.0	0.3
1998	71.4	82.0	14.1	3.6	0.3
1999	83.3	84.9	10.9	3.8	0.5
2000	89.8	86.9	8.8	3.8	0.3
2001	92.1	87.7	7.7	4.1	0.5
2002	99.8	87.7	7.6	4.2	0.5
2003	115.5	87.9	7.4	4.2	0.5
2004	137.3	90.3	4.9	4.0	0.8
2005	152.8	91.5	4.2	3.5	0.8
2006	170.7	92.4	3.3	3.4	0.3
2007	190.5	92.9	2.6	3.4	0.3

Table 8
Fuel mix of agriculture in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Total Mtce	Oil %	Coal %	Electricity %	Heat	NG[a] %
1990	34.6	42.7	44.9	12.3	0.0	0.0
1991	35.6	42.9	43.6	13.5	0.0	0.0
1992	33.7	45.5	39.0	15.5	0.0	0.0
1993	32.8	46.3	38.8	14.7	0.0	0.2
1994	34.7	44.8	39.7	15.3	0.0	0.2
1995	37.5	45.8	38.6	15.5	0.0	0.0
1996	38.6	45.4	38.5	16.0	0.0	0.1
1997	39.5	45.4	38.3	16.2	0.0	0.0
1998	40.0	46.3	38.0	15.6	0.0	0.0
1999	42.4	48.9	31.9	19.1	0.0	0.0
2000	42.9	50.9	29.7	19.3	0.0	0.0
2001	44.4	51.6	27.3	21.1	0.0	0.0
2002	46.9	52.1	27.5	20.3	0.0	0.0
2003	48.7	50.4	30.0	19.5	0.0	0.0
2004	58.2	50.2	32.7	17.1	0.0	0.0
2005	59.7	50.6	31.3	18.0	0.0	0.0
2006	62.4	51.8	29.6	18.6	0.0	0.0
2007	60.8	51.1	29.1	19.8	0.1	0.0

[a] NG=natural gas; data less than 0.05 are presented as 0.0.

Table 9
Fuel mix of the household sector in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Biomass Energy Total[a] Mtce	Commercial Energy Total Mtce	Coal %	Electricity %	Oil %	Heat %	NG[b] %	MG[c] %
1990	263.0	135.8	88.0	3.5	3.4	2.2	1.8	1.0
1991	254.4	135.9	86.6	4.0	3.9	2.4	1.8	1.3
1992	245.7	128.4	83.2	5.0	4.6	3.0	2.2	2.0
1993	247.7	128.0	82.0	5.8	5.4	3.0	1.8	2.1
1994	247.7	122.5	77.1	7.1	7.1	4.0	2.2	2.7
1995	221.4	128.5	76.2	7.8	8.8	3.3	2.0	1.8
1996	219.3	140.4	74.1	8.1	10.4	4.0	1.9	1.5
1997	–	129.3	68.5	9.7	12.1	4.3	2.2	3.2
1998	223.3	108.2	59.9	12.2	15.1	5.9	3.0	4.0
1999	–	109.8	52.9	16.6	17.1	6.2	3.1	4.1
2000	205.7	112.5	48.0	18.3	18.6	7.0	3.8	4.3
2001	–	114.8	45.6	19.7	18.7	6.9	5.1	4.0
2002	–	122.9	43.2	20.0	20.0	7.4	5.5	3.9
2003	–	140.3	43.9	19.6	19.4	8.2	5.4	3.6
2004	270.2	150.5	41.5	20.1	19.6	9.4	5.9	3.5
2005	267.8	163.3	39.9	21.3	18.1	10.8	6.5	3.4
2006	279.8	173.5	35.5	23.0	18.9	11.2	7.9	3.5
2007	260.0	181.9	31.2	24.5	20.5	10.8	9.8	3.3

[a] Include biogas, fuelwood and stalk.
[b] NG=natural gas.
[c] MG=manufactured gas.

Statistically speaking, the reduced role of industry in the oil market means that oil demand in industry has grown more slowly than those in most, if not all, of the other sectors.[6] Whereas the share of oil in total industrial energy demand stayed at around 15–16% between 1990 and 2007 (Table 6), that in the transport fuel mix soared from 58.6% to 92.9% (Table 7); that in the agricultural fuel mix increased from 42.7% to 51.1% (Table 8); that in the household fuel mix shot up from 3.4% to 20.5% (Table 9); and that in the commercial sector's fuel mix rose from 32.0% to 45.5% (Table 10).

[6] During 1990–2007, the average annual growth rate of oil demand in the various sectors was as follows: industry, 5.8%; the household sector, 13.4%; transport, 12.7%; the commercial sector, 8.6%; and agriculture, 4.5% (DITS, various years).

Why has oil demand in industry grown more slowly than those in other sectors? Industry requires petroleum products for three main purposes—motive power, heat and feedstock (non-energy use)—but many subsectors either do not require these energy services or no longer have to depend on oil to access these services.

Three sub-periods can be distinguished according to the growth rate (Table 11). First, during 1990–1996, the trends in oil and energy consumption were similar. The average annual growth rate of oil consumption amounted to 7.1% during 1990–1996 while that of energy consumption reached 6.6%. Second, during 1997–2002, the growth rate of oil consumption decreased, with the average annual growth rate dropping to 3.7%, whereas

that of energy use plunged to −0.4%. Third, during 2003–2007, the picture became even more perplexing: the average annual growth rate of industrial oil consumption jumped to 6.9%, whereas that of industrial energy consumption surged to 13.1%.

The stagnation in the overall energy consumption of the industrial sector during 1997–2002 resulted from the decrease in energy use of several subsectors, such as chemicals, non-metallic minerals, textiles, machinery and equipment, paper and pulp, with their respective average annual growth rates of these ranging from −6.6% to 1.8% during this period (Table 12).

The decline was brought about by (1) Asian Financial Crisis, which shrank domestic and foreign market, (2) the reform of state-owned enterprises (SOE), which down-sized the SOEs, and (3) data inaccuracy. The SOE reform in the mid-1990s reduced the production levels of certain industries, especially textiles, chemicals, ferrous and nonferrous metals production, non-metallic materials, and coal extraction, where state control allowed for greater intervention (Lewis et al., 2003). With fewer outputs, fewer energy inputs resulted.

Furthermore, our interview with an official in 2008 confirms that China's industrial energy demand data actually include both productive and non-productive energy. This means when the SOE reform removed a wide range of socialist community services that were provided for the workers, it simultaneously removed a certain proportion of non-productive energy requirements within their firms. In other words, the reform was responsible for both productive and non-productive energy use decline in the sector.

Table 10
Fuel mix of the commercial sector[a] in China, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Total Mtce	**Oil** %	**Electricity** %	**Coal** %	**NG**[b] %	**Heat** %	**MG**[c] %
1990	37.3	*32.0*	*7.5*	*58.3*	*0.4*	*1.3*	*0.6*
1991	41.1	*36.5*	*8.0*	*53.1*	*0.3*	*1.4*	*0.6*
1992	44.8	*41.7*	*8.4*	*47.4*	*0.2*	*1.4*	*0.7*
1993	57.5	*46.5*	*8.2*	*40.8*	*2.2*	*1.4*	*1.0*
1994	38.1	*13.4*	*14.8*	*67.3*	*0.7*	*2.8*	*0.9*
1995	52.1	*47.4*	*8.4*	*41.3*	*0.4*	*1.9*	*0.7*
1996	59.1	*51.2*	*9.9*	*35.7*	*0.5*	*1.5*	*1.1*
1997	51.3	*60.6*	*12.2*	*23.4*	*0.4*	*2.5*	*0.9*
1998	53.3	*57.2*	*15.0*	*24.1*	*0.8*	*2.1*	*0.9*
1999	59.3	*58.0*	*19.4*	*18.9*	*0.8*	*2.2*	*0.7*
2000	60.4	*59.1*	*21.1*	*17.4*	*0.9*	*0.8*	*0.7*
2001	63.9	*58.1*	*21.8*	*16.3*	*1.2*	*2.0*	*0.7*
2002	67.0	*56.7*	*23.1*	*16.4*	*1.2*	*2.1*	*0.6*
2003	72.7	*52.7*	*25.9*	*17.4*	*1.2*	*2.1*	*0.6*
2004	85.1	*52.4*	*25.6*	*15.6*	*3.6*	*2.3*	*0.5*
2005	88.1	*50.1*	*29.2*	*14.6*	*3.0*	*2.4*	*0.7*
2006	95.0	*47.8*	*31.1*	*14.1*	*3.6*	*2.8*	*0.6*
2007	97.9	*45.5*	*33.1*	*13.0*	*4.5*	*3.3*	*0.6*

[a] Energy use of the government and public services is subsumed under this sector, following international practice. Also only commercial energy is included.
[b] NG=natural gas.
[c] MG=manufactured gas.

Table 12
Industrial energy consumption by subsector, 1997–2002.
Source: China Energy Statistical Yearbook, various issues and pages.

	1997 Mtce	**1998** Mtce	**1999** Mtce	**2000** Mtce	**2001** Mtce	**2002** Mtce	**AAGR** %
Industry total	719.1	702.5	659.9	664.7	674.5	709.7	*−0.4*
Chemicals	**119.0**	**107.6**	**94.1**	**97.6**	**98.4**	**108.6**	***−5.9***
Construction	8.3	10.8	16.0	17.4	18.6	21.3	*16.6*
Ferrous metals	152.2	142.3	143.6	144.9	150.3	161.3	*1.0*
Machinery and equipment	**35.1**	**31.6**	**30.9**	**28.6**	**29.7**	**32.6**	***−2.9***
Metals	6.4	6.4	6.5	6.3	6.9	7.9	*1.4*
Mining and quarrying	56.9	56.0	54.8	56.9	59.1	60.5	*1.3*
Nonferrous metals	17.9	18.7	19.6	19.9	20.3	23.1	*4.1*
Non-metallic minerals	**105.5**	**99.0**	**98.3**	**97.6**	**93.6**	**86.3**	***−5.5***
Paper and pulp	**14.3**	**13.6**	**12.8**	**13.4**	**13.5**	**15.1**	***−1.8***
Petroleum, coking and nuclear fuel processing	56.9	61.5	57.9	60.9	61.6	64.5	*18.0*
Textiles	**20.4**	**18.6**	**17.5**	**16.9**	**17.4**	**18.8**	***−3.9***
Utilities	43.8	42.4	41.5	40.6	40.4	42.8	*2.9*
Others	**61.5**	**58.5**	**50.6**	**46.5**	**46.1**	**45.5**	***−6.6***

Note: AAGR=average annual growth rate of 1997–2002. Subsectors with negative AAGR are in bold.

Table 11
Industrial energy and oil consumption, 1990–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	Energy			**Oil**		
	Mtce	*AGR (%)*	AAGR	Mt	*AGR (%)*	AAGR
1990	498.0	–	6.6% per year (1990–1996)	55.1	–	7.1% per year (1990–1996)
1991	521.9	*4.8*		59.1	*7.3*	
1992	551.2	*5.6*		61.2	*3.6*	
1993	590.9	*7.2*		63.7	*4.1*	
1994	629.9	*6.6*		69.3	*8.8*	
1995	702.2	*11.5*		73.4	*5.9*	
1996	728.6	*3.8*		82.8	*12.8*	
1997	719.1	*−1.3*	−0.4% per year (1997–2002)	88.2	*6.5*	3.7% per year (1997–2002)
1998	702.5	*−2.3*		90.1	*2.2*	
1999	659.9	*−6.1*		89.2	*−1.0*	
2000	664.7	*0.7*		93.6	*4.9*	
2001	674.5	*1.5*		94.3	*0.7*	
2002	709.7	*5.2*		102.6	*8.8*	
2003	841.1	*18.5*	13.1% per year (2003–2007)	111.9	9.1	6.9% per year (2003–2007)
2004	1011.3	*20.2*		127.7	14.1	
2005	1120.3	*10.8*		127.5	−0.2	
2006	1214.5	*8.4*		135.2	6.0	
2007	1304.3	*7.4*		142.3	5.3	
1990–2007			6.0% per year			5.8% per year

Note: AGR=annual growth rate; AAGR=average annual growth rate.

Table 13
Industrial oil consumption by subsector, 1997–2002.
Source: China Energy Statistical Yearbook, various issue and pages.

	1997 Mt	1998 Mt	1999 Mt	2000 Mt	2001 Mt	2002 Mt	AAGR %
Industry total	88.2	90.1	89.2	93.6	94.3	102.6	*3.7*
Chemicals	**19.3**	**16.6**	**13.6**	**14.6**	**14.0**	**16.5**	***−2.1***
Construction	2.9	2.9	7.5	8.3	9.3	11.0	*34.8*
Ferrous metals	**4.4**	**4.3**	**3.9**	**4.1**	**3.9**	**3.7**	***−3.2***
Machinery and equipment	3.9	3.5	3.6	3.5	3.5	3.8	*1.4*
Metals	0.6	0.7	0.7	0.8	0.8	0.9	*6.4*
Mining and quarrying	9.8	9.2	9.6	10.6	10.8	11.3	*8.7*
Nonferrous metals	1.2	1.3	1.3	1.4	1.4	1.5	*6.9*
Non-metallic minerals	5.3	7.1	7.0	7.3	7.4	7.8	*6.3*
Paper and pulp	0.4	0.5	0.5	0.6	0.6	0.7	*11.6*
Petroleum, coking and nuclear fuel processing	29.8	32.6	28.5	29.6	29.5	31.7	*1.6*
Textiles	1.0	1.3	1.7	1.5	1.5	1.5	*3.7*
Utilities	**2.4**	**2.1**	**2.3**	**2.3**	**2.3**	**2.3**	***−0.7***
Others	7.3	8.1	8.9	9.2	9.2	9.8	*11.5*

Note: AAGR=average annual growth rate of 1997–2002. Subsectors with negative AAGR are in bold.

Table 14
Industrial energy consumption by subsector, 2003–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	2003 Mtce	2004 Mtce	2005 Mtce	2006 Mtce	2007 Mtce	AAGR %
Industry total	841.1	1011.3	1120.3	1214.5	1304.3	*11.7*
Chemicals	131.8	152.4	165.8	184.3	199.8	*11.0*
Construction	24.0	27.4	28.7	30.9	33.4	*8.7*
Ferrous metals	201.6	242.8	308.6	353.6	390.2	*18.1*
Machinery and equipment	36.7	43.5	47.5	*51.9*	56.9	*11.7*
Metals	8.6	9.7	10.6	12.0	13.1	*11.1*
Mining and quarrying	69.6	80.9	83.7	*84.5*	90.8	*7.0*
Nonferrous metals	28.6	33.2	37.3	43.2	51.5	*15.8*
Non-metallic minerals	109.4	152.8	157.4	160.9	161.4	*11.3*
Paper and pulp	16.4	21.5	22.2	23.0	22.4	*8.9*
Petroleum, coking and nuclear fuel processing	73.1	91.2	94.0	94.9	102.4	*9.2*
Textiles	21.7	29.8	34.0	32.2	34.8	*13.5*
Utilities	51.3	55.5	57.5	61.7	62.9	*5.3*
Others	44.3	70.1	75.1	*81.3*	84.7	*19.5*

Note: AAGR=average annual growth rate of 2003–2007.

The other factor that could contribute to the perplexing stagnancy in industrial energy use was China's underreported coal use in the period (Sinton and Fridley, 2000). In the mid-1990s, the central government started to close down inefficient and dangerous coalmines in order to enhance the coal sector's competitiveness. Consequently 23,000 small mines were closed by May 1999 but evidence showed that some of these "closed" mines were still producing coal. Prohibited from purchasing the coal from closed mines, consumers, mostly factories, kept quiet about their purchases and consumption of the "dark" coal, "which would cause it to disappear entirely from statistics" (Sinton and Fridley, 2000, p. 674).

Two other factors made industrial oil consumption grow faster than overall industrial energy use during 1997–2002. First, only three subsectors—ferrous metals, chemicals and utilities—saw moderate declines in oil demand (Table 13), because oil did not have the underreporting problem, and more importantly, most of the subsectors which were subject to the SOE reform did not depend on oil heavily, so the reform did not affect industrial oil demand as much as it did to industrial energy demand.

Second, the launch of the highway expansion program in 1998 increased dramatically the oil consumption of construction sector.

Table 15
Industrial oil consumption by subsector, 2003–2007.
Source: China Energy Statistical Yearbook, various issues and pages.

	2003 Mt	2004 Mt	2005 Mt	2006 Mt	2007 Mt	AAGR %
Industry total	111.9	127.7	127.5	135.2	142.3	*6.3*
Chemicals	20.3	24.7	23.4	27.3	28.8	*9.7*
Construction	12.3	14.2	15.0	16.5	18.2	*10.4*
Ferrous metals	**4.0**	**3.2**	**3.3**	**3.1**	**3.0**	***−6.2***
Machinery and equipment	4.2	5.2	6.1	5.2	5.3	*6.9*
Metals	0.9	1.0	1.0	1.0	1.1	*4.7*
Mining and quarrying	**11.9**	**10.3**	**10.4**	**11.0**	**10.8**	***−2.2***
Nonferrous metals	1.8	2.1	2.3	2.6	2.8	*11.4*
Non-metallic minerals	8.1	8.8	9.5	10.4	10.4	*6.6*
Paper and pulp	**0.8**	**0.7**	**0.7**	**0.7**	**0.7**	***−2.7***
Petroleum, coking and nuclear fuel processing	37.1	48.1	47.4	48.2	52.1	*9.5*
Textiles	**1.3**	**1.4**	**1.1**	**1.1**	**1.1**	***−3.4***
Utilities	**2.7**	**2.4**	**2.2**	**2.3**	**2.1**	***−5.7***
Others	**6.5**	**5.5**	**5.0**	**5.8**	**5.9**	***−1.6***

Note: AAGR=average annual growth rate of 2003-2007. Subsectors with negative AAGR are in bold.

Because the expansion of highway networks requires oil for powering construction machines and petroleum asphalt for smoothing road surfaces. Together with the expanded construction needs induced by urbanization, the oil consumption of this sector jumped from 2.9 Mt in 1997 to 7.5 Mt in 1999 and to 11.0 Mt in 2002, with the average annual growth rate shooting up to 34.8% during 1997–2002.

The average annual growth rate of industrial energy consumption rebounded dramatically during 2003–2007 as a result of the rapid growth in the energy consumption of all of the subsectors. The respective average annual growth rate of each subsector's energy consumption during 2003–2007 ranged from 7.0% to 19.5% (Table 14).

In contrast, since 2003, the average annual growth rate of industry's oil consumption has been slower than that of its overall energy consumption. Two factors have contributed to this. First, despite the rapid growth in overall energy use in some subsectors, including textiles, mining and quarrying, utilities and some other manufacturing industries, there have been absolute declines in their oil consumption (Table 15), resulting from the dropping share of oil in their respective fuel mix. For example, the energy consumption of the ferrous metals industry, the largest energy consuming industry, grew by 18.1% per year during 2003–2007 whereas its oil consumption fell by 6.2% per year in the same period. This was in part because oil has played an increasingly smaller in ferrous metal since the 1980s, and the share of it in the fuel mix fell further to 1.5% in 2005, brought about by electrification and expanded use of gaseous fuels (DITS, various years).

Second, some energy-intensive industries are not oil intensive in nature, and hence there is not a proportional increase in oil consumption with energy demand. The non-metallic minerals industry, for example, is an energy-intensive industry, and was the third-largest energy consumer within the industrial sector in 2005, representing 14.0% of overall industrial energy consumption. However, the sector's oil consumption accounted for only 7.5% in total industrial oil use in 2005. This is because oil has never played an important role in this industry—from 1991 to 2005, the share of oil in its fuel mix ranged only from 7.5% to 10.8% (DITS, various years).

Recently, the key contributors to industrial oil demand in China are the petrochemical and construction industries (in

Chinese statistics, the petrochemical industry includes segments of the chemical industry and petroleum, coking and nuclear fuel processing industry), which together accounted for almost 70% of total industrial oil demand in 2007 (DITS, various years).

Besides, the construction sector has emerged as a significant oil consumer since the Asian financial crisis during 1997–1998, as the central government aimed at stimulating the economy, creating jobs and meeting people's transport and residential needs by improving infrastructure. As the Chinese government released a 4-trillion yuan (about US$586 billion) economic stimulus plan in late 2008 to boost the economy (People's Daily Online, 2008), the role of construction oil demand will remain strong.

Lastly, two major shifts in industrial oil mix are worth noting. First, the share of naphtha in total industrial oil demand increased from 17.7% in 1990 to 29.6% in 2007 (DITS, various years; IEA 2009b). The major consumer of naphtha is the chemicals industry. In China, naphtha serves mainly as feedstock for the manufacture of ethylene and production of synthetic ammonia, a raw material used to produce nitrogen fertilizer. The Chinese ethylene industry has seen astonishing growth since the 1990s and thus naphtha is increasingly important to Chinese industry. In 2005, China surpassed Japan to rank second in the world in terms of ethylene production capacity, behind the United States. Furthermore, most of the increase in Asia's ethylene production capacity will be in China, and by 2015, China will have as much capacity as Japan, South Korea and Taiwan combined. All of the new capacity will be naphtha based (McConnachie, 2008). Currently, about 70% of the raw material for the production of ethylene is naphtha, so the rapid development of the ethylene industry is an important driver of China's naphtha consumption. In contrast, the role of naphtha in fertilizer production is smaller. It accounted for about 10% of total feedstock for ammonia production in 2005 (IEA, 2007).

Second, the importance of fuel oil, a petroleum product for producing heat, declined dramatically, with its share plunging from 32.9% of total industrial oil demand in 1990 to 14.4% in 2007. This is because it has gradually been replaced by other heat-generating energy sources, including coal, electricity, natural gas, manufactured gas and LPG. Industrial fuel switching for heat production dates back to the 1980s, when the government decided to convert most of the oil-fired industrial boilers into coal-fired ones. Because of this policy, more than 90% of industrial boilers are now coal fired (Leung, 2009). In addition, factories chose electricity, natural gas, manufactured gas and LPG over fuel oil because these sources produce heat with greater efficiency and fewer pollutants. The Chinese government developed a strategy to limit industrial oil consumption in the Tenth Five Year Plan (2001–2005) by setting up fuel oil consumption targets for the power, chemicals, ferrous metals and non-metallic minerals industries (Leung, 2009). The electrification of the ferrous metal industry, the largest energy consumer within the industrial sector, contributed greatly to the decreased share of fuel oil in total industrial oil demand.

4.2. Transport oil use

International experience shows that a country's economic growth is usually accompanied by an increase in transport energy use: the relation between transport's share of total energy consumption and per capita GDP has been almost linear worldwide for the past 30 years (Schäfer, 2005). This empirical conclusion seems applicable to China: China's transport energy demand grew 10.4 times, equivalent to the almost 11-fold growth in the GDP, from 1978 to 2005 (Zhang et al., 2007).

Transport appears to account for only a small share of China's total energy use. Its energy consumption rose from 40.1 Mtce in 1990 to 190.5 Mtce in 2007, with its share in total final energy use expanding from 5.2% to 10.4%. The current share of transport in final energy consumption is similar to that of India (10.3%), but substantially smaller than that of Russia (22.5%), the world average (27.5%) and the US (41.3%).[7]

McCreary and Gu (1996) attribute the small proportion of transport energy use to Mao Zedong's national spatial planning in the 1950s. At that time, Sino-Soviet relations were deteriorating. Fearing invasion by the Soviet Union, Mao established industries in isolated villages with minimal road connections. Long-distance transport networks are a recent phenomenon; hence, the energy consumption of this sector remains small.

A more important reason for transport's small share of total energy demand is that China's energy statistics system is different from the international norm. In China's case, transport energy consumption data cover only the energy use of transport-related enterprises, and the energy used for the transport activities of individuals and non-transport institutions is respectively recorded as household and commercial sector energy consumption instead.[8]

Transport can be regarded as a "captive market for oil," as there is no cost-effective and efficient substitute for oil in this sector. The share of oil in the transport fuel mix jumped from 58.6% in 1990 to 92.9% in 2007, whereas that of coal plummeted from 38.6% to 2.6% and that of other fuels increased from 2.8% to 3.7% (Table 7). Transport's oil consumption skyrocketed from 16.4 to 121.3 Mt between 1990 and 2007, and its share in total end-use oil demand also jumped from 17.6% to 35.9%.

The key forces driving China's transport oil demand include (1) the rapid growth of road transport, (2) the dieselization of rail transport and (3) the remarkable development of domestic air transport. The Chinese government does not publish the energy demand data of different transport modes, but the IEA (2007, p. 298) estimates that road transport accounted for over 80% of the overall growth in transport energy use during 1990–2005. As road transport is fuelled overwhelmingly by oil, its rapid expansion is assumed to have contributed significantly to the increase in transport oil demand.

Why has road transport grown so quickly? The rapid increase in vehicle ownership in China—from 5.5 million in 1990 to 43.6 million in 2007 (NBS, various years)—is a result of economic growth, the lower cost of vehicles and the desire of Chinese people to own motorized means of transport, especially light-duty vehicles (LDVs).

First, economic growth is the main reason for the increase as it raises personal income (as long as the population growth rate is lower) and enhances the affordability of vehicle ownership for individual citizens. Studies show that when the per capita GDP of a country surpasses US$1000, the vehicle ownership of that country takes off (Sheer and Wang, 2007), and an increasing number of Chinese have achieved such an income level.

[7] Data for 2006 (see IEA, 2009a).

[8] Interview with an anonymous staff member of the National Bureau of Statistics of China on 2 February 2008 (see also Wang, 2006; Berrah et al., 2007, Annex 1.3; Sinton and Fridley, 2002). In recent years, an increasing number of national and international energy specialists have begun to recognize this "problem," but have not yet reached a consensus on how to recategorize the data following international norms. At the 31st IAEE International Conference, which was held in Istanbul, Turkey, in 2008, a Chinese energy expert, who worked with Chinese senior energy officials, informed me that the central government has also recognized this issue and is considering publishing a new collection of China's energy data in the future. In the meantime, we continue to use the current set of data. We strongly believe that with proper explanation, these data are still very valuable for the study of China's energy.

This also related to the strong desire of people to become vehicle owners, which has been fostered in part by China's pro-auto policy. The Chinese government's *1994 Auto Policy* designated the automobile industry as a pillar of economic development and officially encouraged private ownership of vehicles (Gallagher, 2006; Shalizi, 2007). In addition, reflecting the government's position, the expansion of the transport infrastructure has been largely road based. The total length of the highway network increased from 1.0 million km in 1990 to 3.6 million km in 2007 with an average annual growth rate of 8.7%, which was much higher than that of railways (1.8%) or inland waterways (0.8%) (NBS, various years). Further, there have been improvements not only in cities but also in rural areas, with highways geographically accessible to more than 90% of rural residents by the end of 2002 (Ji and Chen, 2006). All of these factors have encouraged people to buy vehicles.

Second, China's entry into the WTO triggered a price war among domestic auto manufacturers at the beginning of 2002, which substantially lowered the cost of owning a vehicle. Domestic products accounted for more than 95% of vehicle sales in China (Gallagher, 2006).

Third, besides passenger vehicles, freight vehicles also drastically grew with economy in China. OPEC (2009) finds that even in developed European cities, where the number of personal vehicles has reached market saturation, the number of freight vehicles, mainly trucks, still increases quickly, providing that logistics is the prerequisite of economic development. It is evident that passenger and freight transport have grown equally fast in China: While total energy demand by cars has increased 243.6% during 1990–2005, that by trucks has risen 244.4%. And in 2005, trucks accounted for 48.2% of total road transport energy demand; cars, 38.8%; and buses and motorcycles, 13.0% (IEA, 2007, p. 297).

Besides, rail transport fuel switching also contributed greatly to the increase in transport oil consumption during 1990–2007. Steam locomotives, powered by coal, are famously low in energy efficiency and high polluting. To increase overall energy efficiency and lower the environmental impact of rail transport, the government gradually replaced steam locomotives with diesel and electric ones. The switch began when China stopped producing steam locomotives in 1988. New types of locomotives, including the *Dongfeng* series (diesel powered) and *Shaoshan* series (electricity powered) were developed (Xue et al., 2002). In 2002, steam locomotives ceased to operate in China. The share of diesel locomotives in terms of length of the operating railway increased from 20.8% in 1985 to 62.2% in 2007, while that of electric locomotives increased from 8.0% to 37.8% (NBS, various years). The dieselization of rail transport has raised the total transport oil demand.

The remarkable development of domestic air transport in China also led to higher transport oil demand (note that the energy use of international airlines is not subsumed under domestic energy consumption). From 1990 to 2007, the number of China's domestic air routes increased from 385 to 1216; domestic air passenger transport increased from 15,766 million persons-km to 217,331 million persons-km; domestic air freight transport increased from 316 million tons-km to 4157 million ton-km (NBS, various years); and jet fuel consumption soared from 0.9 to 16.7 Mt (DITS, various years).

4.3. Agricultural oil use

Despite the rapid growth in the industrial and service sectors, agriculture remains a pillar of the Chinese economy, ensuring a stable supply of food and providing an important source of employment for the population. The sector accounted for 11.3% of the GDP and 40.8% of total employment in 2007, with 314.4 million working farmers—more than the entire US population (NBS, various years).

Compared with other sectors, agriculture is neither a large energy nor a huge oil user. In 2007, it accounted for only 3.3% of total end-use energy consumption, with oil representing 51.1% of total agricultural energy use in 2007, up from 42.7% in 1990 (Table 8). The sector's oil demand doubled from 10.3 Mt in 1990 to 21.3 Mt in 2007, and accounted for 6.3% of total end-use oil consumption in 2007, down from 11.1% in 1990.

Although farmers consume a relatively small amount of oil, ensuring that they receive a reliable and affordable oil supply is a serious challenge. First, agricultural oil demand is highly seasonal because of the nature of agricultural activities. The seasonal jump in oil demand is intense and short term (Tan et al., 2006). It is often difficult for the government and state-owned oil companies to distribute sufficient oil in a timely manner to the group of more than 300 million farmers via the disjointed rural market channels.

Second, because it is fragmented, the 300 million plus agricultural group lacks bargaining power. Many rural retailers are unwilling to sell oil to farmers because the quantity of oil per purchase is small. Unless farmers are willing to buy lower quality oil or pay higher prices, rural oil suppliers do not have much incentive to sell them oil; they would rather sell to large buyers, such as rural factories. To ensure oil supply to farmers, the central government and state-owned oil companies have allotted a certain percentage of retail oil for agricultural use only. This policy is effective in some regions but has sometimes caused inconvenience to farmers. For example, rural retailers, following government orders, must retain some of their oil for sale to farmers. However, it is difficult to identify whether a client is a farmer and to ensure that the client will spend the oil on agricultural activities rather than reselling it for profit. Hence, sellers often require farmers to bring their agricultural machines with them when they buy the oil. This wastes much oil because of the moving of the machines, and causes great inconvenience to farmers when oil stations are far away (Tan et al., 2006).

Agriculture's oil demand is driven by agricultural mechanization. The total power of China's agricultural machines soared from 287,100 mega-watt (MW) in 1990 to 765,896 MW in 2007, with approximately 80% of these machines powered by either diesel or gasoline (Editorial Committee on China Agricultural Machinery Industry, various years).

4.4. Household and commercial oil use

Household sector has raised its commercial energy demand from 135.8 to 181.9 Mtce during 1990–2007 and has constantly required a tremendous amount of traditional biomass energy—biogas, stalk and firewood—which amounted to 200–280 Mtce in the same period (Table 9). Household oil consumption soared from 1.4 to 22.7 Mt and in 2000, 53% of such oil use was for cooking and water heating (Chen et al., 2006, p. 58). The growth in liquefied petroleum gas (LPG) use, especially in urban area, was the key driver of total household oil consumption growth.[9]

Many studies have found that the changes in China's household fuel mix reflect the model of energy transition. This model

[9] In the 1990–2007 period, the share of LPG, used mainly for cooking and water heating, in total household energy demand rose from 55.7% to 70.9%; that of gasoline, used for powering vehicles owned by individual households, increased from 6.3% to 19.2%; that of diesel rose from 0.1% to 9.1%, with most of it going to fuel the vehicles owned by individual households; that of kerosene, a petroleum product for lighting, water heating and cooking, dropped drastically from 36.8% to 0.9%; and that of refinery gas, little used in the household sector in the early 1990s, declined from 1.1% in 1990 to 0.6% in 1995, and has remained at 0% since 1996 (DITS, various years).

summarizes the experience of household fuel selection in the post-war era. It holds that when households become more affluent, they switch from low-grade fuels, such as charcoal or fuelwood, to higher-grade ones, such as kerosene, and ultimately, to "modern" fuels, such as LPG, natural gas and electricity.[10]

Among energy transition and household fuel selection factors, income level and fuel options have had the greatest effect on household LPG consumption. First, the difference between urban and rural areas helps to confirm that the rise in personal income has boosted LPG consumption. From 1990 to 2007, the annual per capita disposable income of urban households increased rapidly from 1510 to 13,786 yuan, while that of rural households increased from 686 to 4140 yuan (NBS, various years). In this period, LPG consumption by urban households jumped from 1.6 to 12.7 Mt and that of rural households increased from 0 to 3.4 Mt (DITS, various years). The increase in rural LPG use has been less pronounced in part because the importance of traditional biomass energy use in rural China has been maintained during the past 25 years and coal use was only moderately substituted by "modern" energy—no significant transition in rural energy use patterns is seen (Pachauri and Jiang, 2008).

The second factor of energy transition that has affected household oil consumption is fuel options, that is, the availability of LPG and other fuels. At the aggregate level, household oil consumption during 2004–2005 leveled off, edging up from 17.8 in 17.9 Mt, in part because of the replacement of LPG by natural gas in urban areas. The use of natural gas in these areas has been growing quickly with the construction in recent years of a nationwide distribution infrastructure under a policy to shift households from solid fuels to gaseous fuel and electricity.

The future of the household LPG market is cautiously bright. The natural gas network cannot reach most rural areas because of economic infeasibility; thus, LPG is still the most available "modern" gaseous fuel in rural areas as the penetration capacity of bottled LPG is higher. However, the unique success in China's rural household biogas development—by 2006, 22 million households were installed with biogas digesters—has limited the rural expansion of LPG (Gan and Yu, 2008).

The commercial sector is also a significant oil consumer in China and merits more comprehensive analysis.[11] During 1990–2007, the share of oil in this sector's fuel mix increased from 32.0% to 45.5% (Table 10), with the consumption of oil growing from 8.4 to 30.1 Mt.[12]

5. Concluding remarks

This study has investigated the development of sectoral oil consumption in China since 1990. The growth in Chinese oil consumption has accelerated remarkably since the 1990s in response to dynamic growth in industry and transport, whose combined share of total end-use demand ranged from 72% to 78% during 1990–2007.

Despite the drop in the relative importance of industry to oil consumption, this sector is still a significant contributor to the growth in total oil consumption because of its dominance in the economy. The magnitude of change due to rapid industrialization in post-reform China is almost unimaginable. China has come to be regarded by many as the "world's factory," and in 2008 exported in a single day more than it exported in all of 1978 (Zakaria, 2008, p. 89). Although the global demand for Chinese products has dropped drastically since late 2008 because of the economic crisis, the industrial sector is still supported in part by domestic consumers and government stimulus plans (Economides and Lee, 2009). The Purchasing Managers' Index (PMI) for China's manufacturing sector rebounded to 55.0% in September 2009, up from 45.3% in January 2009 (Forbes, 2009b). Although the export market has shrunk, the domestic market remains relatively healthy—the general public still requires necessary goods, and the government's infrastructure expansion plans, as part of the economic stimulus package, call for many basic materials and much machinery and equipment.

Since 1994, China has been a pro-auto country. The central government's pro-auto policy, which was introduced in 1994 and renewed in 2004, promotes domestic auto production and car ownership, and has changed the transport landscape tremendously. Total vehicle ownership expanded almost eight times during 1990–2007, and road transport, which is driven overwhelmingly by oil, has become the dominant mode, representing about 65% of total end-use energy in the sector in 2005. It is predicted that the share will grow to 70.8% by 2015 and 77.4% by 2030 (IEA, 2007, p. 297). Recent developments seem to support this projection. In January 2009, car sales in China outstripped those in US for the first time (Forbes, 2009a). The average annual growth rate of car sales during 2007–2030 is estimated to stay at 8.4% (OPEC, 2009).

There is a need for the reevaluation of the pro-auto policy as it has related benefits and costs. The policy was introduced based on the rationale that the promotion of the automobile industry could accelerate economic growth and create jobs via backward linkages and the spillover effect. However, it is compromising the efforts of China's oil security policy. On the one hand, the central government has made great efforts to maintain oil security. It paid premium costs to build the West-East Gas Pipeline, transnational oil and gas pipelines, strategic petroleum reserves and coal-to-liquid plants, and to gain ownership of equity oil in countries governed by unpopular regimes, such as Omar al-Bashir's government in Sudan. On the other hand, private car ownership is being encouraged, creating "a captive market for oil." Some believe that China is imitating the American model of transport and spatial development (Gallagher, 2006; Berrah et al., 2007). A car culture is springing up in many rich cities, including Beijing and Guangzhou, which is causing serious congestion and pollution problems.

Moreover, the benefit of the pro-auto policy seems to be less than expected. The domestic auto industry has failed to export its products because their quality is too low (Gallagher, 2006). The industry has also failed to absorb and make use of more advanced, foreign technologies, partly because foreign partners have been reluctant to share their know-how with a potential competitor, that is, China. The central government should take action to divert the pro-auto development path now, because such change is possible only when the vehicle stock is still small. Once the

[10] See Leach (1992), Chow (2001) and Pachauri and Jiang (2008).

[11] For the sake of simplicity and convenience, the energy consumption of the government and public services is subsumed under the category of commercial energy consumption, following international practice. It is pointed out that the coverage of the commercial sector in energy studies does not overlap closely with that in economics research. This sector's energy consumption involves a wide range of energy activities, including the energy consumption of the service industries (except for transport enterprises), public facilities, government offices and the military. In addition, given the heterogeneous nature and serious lack of energy consumption statistics of the commercial sector, a thorough investigation of this sector across the country is too difficult to carry out. For methodological and empirical discussions on commercial building energy use, see the special section "China Energy Efficiency," in *Energy Policy* 37, No. 6 (June 2009), edited by Jing Zhao.

[12] There was also a drastic change in the oil mix of the commercial sector during 1990–2007. The share of diesel, used mainly for fueling vehicles and producing heat and motive power for a myriad of machines, soared from 28.6% to 48.5%; that of gasoline, virtually all of which is used for fueling vehicles, declined from 52.3% to 43.2%; that of kerosene, used mainly by the Chinese military in the form of aviation kerosene, dropped from 15.3% to 1.6%; and the combined share of LPG and fuel and crude oil increased slowly from 3.7% to 6.7%.

infrastructure is built and vehicles are purchased, a new status quo will be established.

It is obvious that Chinese oil consumption will continue to rise, despite a temporary setback in 2009. The rapid development of road and air transport will contribute significantly to its growth. The petrochemical industry will consume more oil to meet the increasing demand for its products, and construction oil use will also grow rapidly because of continuing urbanization and infrastructure expansion, accelerated further by Beijing's recent economic stimulus package. Household energy transition will go on and LPG will be progressively chosen over coal and other traditional fuels, but LPG is facing competitors—natural gas and manufactured gas in urban area as well as biogas in rural area.

The structural change in the economy will increase the oil demand in the commercial sector, but will not reduce the absolute amount of agricultural oil consumption. Chinese agricultural mechanization will continue, and reliable oil supply to farmers will remain a serious challenge because of the seasonality of the agricultural oil market and fragmented structure of the market itself. In addition, although transformation oil consumption will be further reduced, refinery oil use will continue to grow, and the impact of oil demand by private power generation in the event of widespread power shortages could be great.

The military, which is actively developing its naval and air power, will also require more oil to fuel its military forces, including fighters, bombers, armored vehicles, destroyers, conventional submarines and, in the foreseeable future, aircraft carriers (Taipei Times, 2009).

Lastly, while China is actively embracing renewable energy, it, unlike the States, is not doing so mainly for oil security because the role of oil in China's fuel mix is already small. Whereas the States wants to reduce oil use and enhance energy security by using more renewable energy, China develops renewable energy to lower its dependence on coal, the single largest source of its air pollution and energy inefficiency. The link between renewable energy and oil is less pronounced in China.

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